Paper presented at the HSci 2006 - 3rd International Conference on Hands-on Science, 4th - 9th September, 2006, Braga, Portugal, proceedings published by University of Minho (http://www.hsci.info/hsci2006/index.html).

On the feasibility to include contemporary Science concepts in the Primary school curricula – a retrospection into two case studies(*).

Miltiadis Tsigris,
Chemist Teacher assigned to The University of Crete, mtsigris@edc.uoc.gr

P. G. Michaelides,
Professor, Department for Primary Education, The University of Crete, michail@edc.uoc.gr

(*)This work has been partially funded by the European Commission (project "Hands-on Science" contract number 110157-CP-1-2003-1-PT-COMENIUS-C3). Neither the Commission nor the authors of this work may be held responsible for any use of the information provided here.

Abstract. *In contemporary knowledge conscious societies, the effective Science and Technology teaching is of paramount importance. One very significant parameter of an effective Science and Technology teaching is the actual syllabus involved in the school curricula. In general, the syllabus reflects the Science of the previous century. Very important Science advances like relativity, quantum mechanics, statistical physics, systems, etc are at most given a short simplistic description if not omitted at all. The reason usually quoted is that these issues are complicated and require advanced mathematics consequently they are beyond the capabilities of the students. We have challenged this widely apprehended doctrine by trying to teach the basic concepts of relativity and of systems to 5th and 6th grade students (ages 11-12 years). The results from these test cases were encouraging and have been already presented in the Hands on Science 2005 International Conference. In this work, we examine the two test cases from the viewpoint of the feasibility of a large-scale inclusion of contemporary Science concepts in the Primary school curricula.*

Keywords. Science teaching, primary school curriculum, primary education.

1. Introduction

The contents of the Science syllabus in school curricula have a significant impact on the effectiveness of Science and Technology Literacy which is of paramount importance to the contemporary knowledge conscious societies [1]. For an adequate Science and Technology Literacy knowledge on contemporary Science concepts is necessary [2]. However, concepts like quantum mechanics, relativity of space-time, statistical physics, elementary particles and cosmology, materials science and solid state physics, radioactivity - even more traditional topics like (micro) electronics - and other recent developments are missing from school curricula although many of them are (more than) a century old.

One often quoted reason for this omission is the statement that these concepts are very abstract and difficult to understand, thus they are not appropriate for the Science syllabus in schools. . In this work we examine the validity of this statement which is (to our opinion) a widely accepted belief rather than an empirical fact

2. Methodology.

In order to test the feasibility of teaching contemporary Science concepts to students of the compulsory education we proceed as follows:

1. The basic notions from a selected contemporary Science topic were located and analysed. It is understood that the objective, for the compulsory education at least, is to teach the understanding of the basic notions of the selected topics and not the full functioning of the model with all the (complicated) mathematics.
2. A class (grade) from the compulsory education level was chosen as a test case for the teaching of the basic concepts located in the previous step. Grades 5 (age 10 to 11 years) to grade 7 (age 12 to 13 years) were thought appropriate. The reasons are: a/in a Piagetian context the students are old enough to be at the stage (or approaching the stage) of formal logic, b/they, usually, have not

exposed to a systematic (analytical) Science course consequently they have not any representation related to the concepts to be taught (presumably – see next step).

3. The basic steps for a teaching intervention were planned.
4. Before the teaching intervention was actually delivered, a questionnaire was given to the prospective students. Its purpose was to locate the students' relative (pre) concepts on the subject to be taught and adapt appropriately the details of the teaching intervention. Possible influences of the society (in a Vygotsky's context) could also be traced.
5. The teaching intervention was delivered. This included at least two sessions of 1 or 2 teaching hours each separated by an interval of one or more weeks. At the last session a questionnaire was again given to the students.
6. For every one of the Science topics selected at the first step, a report with the outcomes from the questionnaires together with the comments of the teacher who delivered the teaching intervention (action research) was prepared.
7. The reports prepared at the previous step were analyzed by the authors of this work who had also been involved during the planning of the teaching intervention as 'councillors' on the didactics and on the subject matter of the topics selected.

3. Implementation.

The whole work was organized within the degree dissertation course of the Department for Primary Education of The University of Crete. The choice of Grades 5 and 6 (ages 10 to 12 – primary school in Greece) as the classes for the test cases was a consequence. The reports prepared became (part of) the graduate dissertation of the students involved. Two specific topics were selected, their selection influenced by the students – researchers who actually delivered the teaching.

3.1 Systems and Systemic thinking.

The 1st topic selected was on the concept of 'system'. The student researcher was already a teacher in primary education schools with a diploma from academy attending further education courses at the Department for Primary Education of The University of Crete in order to obtain a primary teacher's University degree. The basic concepts located for this topic were the system as a complex concept consisting of entities (subsystems) with direct links (dependencies) between them. The skill to recognize a system with its various constituents and the deduction by the school students of indirect links (dependencies) of the type ***constituent a*** *is linked to (depends on)* ***constituent b***, ***constituent b*** *is linked to (depends on)* ***constituent c*** *consequently* ***constituent a*** *is linked to (depends on)* ***constituent c*** were among the aims of the teaching intervention [3]. Characteristics of systems, e.g. relations between different parts of a system, are included as factual knowledge in the school syllabus, for example (some) relations between constituents of an ecosystem. Consequently the students, who, in a Piagetian context, are entering or approaching the stage of formal logic, are not faced with a concept totally abstract to them. However, these basic concepts are mentioned in a fragmented way mostly as (direct) dependencies between parts of an ecosystem and although the word system with its everyday meaning is mentioned quite often in the textbooks, the concept of '*system*' as a technical term of systemic theory is missing [4]. The planned teaching was delivered to students of the 5th and 6th grade (ages 10 to 12) of the classes the student researcher was teaching. It should be noted that the word system is a commonly used word in many expressions of everyday life and many preconceptions from the students are expected. As a result, a successful teaching intervention will show clearly, even with a relatively small sample.

Some of the results obtained from the experimental teaching of the topics selected are [6]:

1. The pre-test indicated that students perceived 'system' as something repetitive (e.g. clock) or something planned (e.g. homework reading) or something involving human action (e.g. irrigation) or humans themselves (e.g. the human body). Even 'system' as a complex or corporate notion (e.g. a tree or a tree wood) was not perceived clearly as a system. The post-test carried out one month after the teaching intervention showed a remarkable improvement on the perception of system. Not only they exhibit a working knowledge definition of 'system' but they

can also justify it by indicating interrelations between its parts.

2. The pre-test indicated that all students stayed within the direct one to one relations. At the post-test 5 out of the 20 students were able to immediately indicate also indirect relations (dependencies). Although this number is rather low it is very encouraging in view of [3]. This is further supported by the observation that during the discussion following the post-test [7] almost all the students were able, in a two step process, to perceive also indirect relations which they had not indicated at first so that a more thoroughly planned teaching intervention may have had better results. The fact that of the 5 students who showed a clear evidence of advance towards a systemic thinking the 4 were girls (who mature earlier) combined with Vygotsky's context of the Zone of Proximal Development reinforces our statement.

3.2. Einstein's Theory of Relativity.

The 2nd topic selected was on Einstein's theory of relativity. The student researcher was a final year student at the Department for Primary Education of The University of Crete whose most of the graduates of the Department work as primary school teachers. The basic concepts located for this topic were the meaning of simultaneity and the time – space dependence on the state of motion of the observer (relativity of space and time). As it was discovered that *speed of light*, *black holes*, etc are words familiar to school students through comics, science fiction, mass media, etc their meaning were also included to the teaching plan. On this topic nothing is explicitly included in the school curricula although the phrasing of the textbooks suggests an absolute (Galilean) space-time continuum [5]. This is in dissimilarity to the previous 1st topic selected and should be taken into account in comparing the results. The planned teaching was delivered in a 6th grade class (age 11to 12) of a primary school where the student researcher was doing his 4th level school practice undergraduate course.

For this 2nd topic selected the implementation was done using a primary school class of 6th grade (ages 11-12 years) [8]. There were 16 students in the class 12 of which attended all 5 meetings. The student researcher had 5 meetings with the class. The 1st meeting was to familiarize with the students and collect the pre-test questionnaire. In the 2nd, 3rd and 4th meeting the teaching intervention was made in 3 separate days about one week after the 1st meeting. At the end of every teaching a questionnaire was completed on formative assessment purposes. The final (5th) meeting was done about one week after the last teaching took place and the post-test questionnaire was collected. The main results are:

1. The pre-test indicated that the students knew that distance time and mass are measured in (kilo)meters, hours (seconds), (kilo)grams, that an object weight is due to earth's gravity and it would be less in the moon. They also had heard about galaxies and black holes, presumably an influence of (science)fiction through TV, comics and DVD's.
2. In the 1st teaching hour the concepts of motion, of the speed of light and of the dependence of the weight of an object upon the gravitational attraction of the earth were introduced. Clarifications on the students' understandings on galaxies and stars were also provided. At the end of this teaching, the students were able to infer that an object in moon should appear lighter and, if left to fall, it will need more time to reach the ground than the time needed in a similar situation on earth.
3. In the 2nd teaching hour the students were introduced to the concepts of the speed of light (as constant in all frames and as an upper limit for any material body), of the dependency between the speed and the mass of an object and of the relativity of space (time dilatation - space contraction) within the context of Einstein's theory of relativity. At the end of this teaching, the majority (>60%) of the students answered correctly the questions on the speed of light as an upper limit and on time dilatation. On the other issues the correct answers were: for the speed of light constancy 4/10, for space contraction 3/10 and for the mass dependency 4/10 with another 2/10 answering 'do not know' [9].
4. In the 3rd teaching students were exposed to a presentation on the shapes of galaxies, the expansion of the Universe and the evolution of stars [10]. Their attention was also drawn on the observable perception that 'their weight seems to change in accelerating (decelerating) situations, e.g. at the start (stop) of an elevator on the take off (landing)

on an aeroplane, cornering (braking) of a car, etc.' as an introduction to the concept of equivalence between the inertia and the gravitational mass. At the end of this teaching, all the students answered correctly the questions about the shape of the galaxy and those relating acceleration to gravity. Again, about 1/3 of the students answered correctly the question of a more advanced character.

5. One week after the last teaching a 'post-test' questionnaire was collected. In this the majority of the students (>70%) answered correctly. Although the time elapsed is short, the questionnaire indicates an effective teaching of the corresponding subjects. The increase of the correct answers in comparison with the questionnaires completed at the end of the teachings is under investigation. Possibly this is due: a/to a better phrasing of the questions of the final questionnaire, b/to an informal peer discussion between the students after the teachings and the completion of the questionnaires. The fact that the 'do not know' answers have diminished may support this view.

4. Commentary

From the previous two (small scale) test-cases it is evident that 5th and 6th grade (ages 10-12 years) primary school students:

- are capable to conceive the basic concepts of '*system*' and of the relativity of space and time.
- are, to a significant percentage at least, capable to comprehend more advanced notions like '*systemic thinking*' or the relation of weight to acceleration.
- the difficulties on some advanced concepts may be considered as similar to the difficulties in understanding other topics and, with a more carefully planned teaching (e.g. based on individual teaching approaches) may improve the situation.

We may, consequently, expect reasonably that the same results will show up also with other topics as mentioned earlier in **1. Introduction**. Thus, the issue of updating the school Science syllabus acquires a new perspective. Towards this end we briefly indicate some remarks based on our experience from these test cases and, also, from discussions with other colleagues, teachers (including the students – researchers) and students.

a) For every topic the basic concepts should be located and an appropriate teaching strategy should be adopted. This teaching should focus not on the detailed processes and functioning (a scope outside the objectives of the compulsory education) but on the conceptual modelling (representation) of the natural world. The teaching should also try to relate the (new) concepts to other topics and, also, to everyday phenomena.

b) The topics selected should be presented in a coherent way and not as separate unrelated add on modules.

c) There are no previous experiences on the preconceptions of the students and this implies more effort from the teacher.

d) The previous teaching implies a similar mode of initial education for the Science teacher. Science teacher education is usually along two extreme lines, as a specialist training and as a general teacher. The first is usually the case for the secondary and for the technical vocational education. These teachers usually tend to occupy their students with details on data, processes, mathematical formulas etc paying little attention to the general model for the natural world. The second is usually the case for primary education. These teachers usually tend to repeat the textbooks and teach Science as a collection of (unrelated) data and observations. Neither of these seems appropriate for the context under discussion where the teacher should possess and be able to teach e.g. scientific inquiry skills. Further study towards the development of complex cognitive skills and reasoning should always accompany even declarative teaching, which sometimes seems unavoidable. Only this way the 'dogmatic approach' of an 'absolute scientific truth' (similar to indoctrination in a religious class) will be avoided. Otherwise, confusion between science advances and the religious dogma will appear as has repeatedly been observed [11].

e) In both cases the students - researchers observed that the students were approaching the (new) ideas with a 'fresh and innovative' way they had not anticipated. This helped them (the teachers) to clarify their understanding of the subject they were teaching. It unearthed however the real problem, according to us, on the introduction of contemporary Science concepts to the school curricula, i.e. the teachers' competence and their lack of a conceptual understanding of Science. In these two test cases the students researchers did not had a specialist's training in Science [12]. This resulted in extensive consultancy with the authors of this work. As they commented later, they used this experience of theirs to anticipate children's' behaviour and adapt the teaching strategy adopted although in many occasions children surprised them with the (usually simpler) interpretations they assigned to the new concepts taught.

5. Epilogue

Our basic objective that we should put under the test of empirical evidence the general belief that 'children are not able to understand new concepts which scientists have spent a lot of time to understand' has been validated. Children are capable of assimilating contemporary Science concepts. Consequently, a total reform of the school Science curriculum must be done. In view of the comments made in **4. Commentary** this reform should be tested on its different parameters to ensure an efficient contemporary Science literacy, the most critical parameter being the Science teacher (initial) training.

6. Acknowledgements

The comments and cooperation of the students - researchers N. Kountourakis and A. Tsalapakis are greatly acknowledged.

7. References and Notes

[1] P. G. Michaelides, "State of the Art in Science Teaching". In: Divjak S, editor. Proceedings of the International Conference on Hands on Science; 2004 Jul 5-9; Ljubljana, Slovenia. Ljubljana: University of Ljubljana; 2004. pp. 11-17. Invited presentation.

[2] For the necessity on the modernisation of the Science curriculum see George Kalkanis 'Which (and How) Science and Technology Education for Future Citizens?', pp. 199-214 of Vol. II of the proceedings of the University of Cyprus, '1st IOSTE Symposium in Southern Europe – Science and Technology Education: Preparing Future Citizens', Paralimni-Cyprus 29/4-2/5 2001.

[3] It should be noted that in a Piagetian context, the students in this age are mostly in the concrete (and towards the formal) operational stage able (mostly) to one parameter (direct, one to one) relations. Consequently, the expectations here should be limited.

[4] In systemic theory the term 'system' is used to denote a way of organizing our thoughts about reality. It may refer to (material) things (e.g. a machine) or a corporate organization. Although related concepts may be traced back to the works of Norbert Wiener on Cybernetics and of Edward Lorenz (a meteorologist) on Chaos systemic theory, especially applied to understanding and solve complex problems has only recently emerged as a, more or less distinct, scientific branch. For a particular viewpoint see Daniel Aronson, Overview of Systems Thinking (Visited on 13-Jun-2006) in http://www.thinking.net/Systems_Thinking/OverviewSTarticle.pdf.

[5] This is true also for the textbooks in middle and high schools. In most of the University level textbooks the same attitude is also observed.

[6] N. Kountourakis, P. G. Michaelides, 'Contemporary Scientific Concepts in Primary Schools: A Test Case on the concept of Systems', proceedings pp.307-310 of the 2nd International Conference on Hands on Science Hsci2005 – Science in a Changing Education, July 13-16, 2005 – Greece, The University of Crete campus at Rethimno (http://www.clab.edc.uoc.gr/2nd/). A more detailed report may be found in; N. Kountourakis, 'Teaching the concept of system in primary school – introduction to systemic thinking', Rethimno 2005, degree dissertation, Department for Primary Education, The University of Crete (in Greek).

[7] The pre- and post- test questionnaires were complimented by discussions with the students in order to ascertain the validity of their answers. This was triggered by the observation that the students understood the meaning of relation as one sided. For example they understood the word influence as having the meaning of diminishing (in

numbers) or of a negative (on values) notion.

[8] Antonis Tsalapakis, ‘The Theory of Relativity in Primary Education’, proceedings pp. 408-410 of the 2nd International Conference on Hands on Science Hsci2005 – Science in a Changing Education, July 13-16, 2005 – Greece, The University of Crete campus at Rethimno (http://www.clab.edc.uoc.gr/2nd/). A more detailed report may be found in; Antonis Tsalapakis, ‘The Theory of Relativity in Primary Education’, Rethimno 2006, degree dissertation, Department for Primary Education, The University of Crete (in Greek).

[9] Although these figures seem low, in view of the comments made in point 2 of **3.1 Systems and Systemic thinking**, they rather encouraging.

[10] This was done mainly following (provoked?) students questions on the subject. The inexperienced zest of the student researcher played also a role.

[11] It was also observed by the student researcher of the second test case when, answering students questions he entered to recite current views on the origin and evolution of the universe. Many students reacted intensely on reason that it was contrary to what they had learned in the religious class (the bible in this case).

[12] This was rather an advantage because: a/ they were willing to learn without any second thoughts about their image as ‘Knowledge sources’, b/based on our teaching -training experience, secondary education Science teachers (specialist’s training) usually have strong conceptions on what Science is and how it should be taught and very rarely they endeavour to try a different teaching style.